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Microplastics in sea-surface waters surrounding Sweden sampled by manta trawl and *in-situ* pump

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Abstract

Microplastics were sampled in open surface waters by using a manta trawl and an *in-situ* filtering pump. A total of 24 trawl samples and 11 pump samples were taken at 12 locations around Sweden. Overall, the concentration of microplastic particles was higher in pump samples compared to trawl samples. The median microplastic particle concentration was 0.04 particles per m^{-3} for manta trawl samples and 0.10 particles per m^{-3} in pump samples taken with a mesh size of 0.3 mm. The highest concentrations were recorded on the west coast of Sweden.

Fibers were found in all samples and were also more frequent in the pump samples. Even higher concentrations of fibers and particles were found on the 0.05 mm pump filters. Using near-infrared hyperspectral imaging the majority of the particles were identified as polyethylene followed by polypropylene.

Keywords: Plastic pollution, Polyethylene, Polypropylene, Baltic Sea, Skagerrak, Kattegat, Microplastic sampling methods

Introduction

Microplastics in aquatic environments have become a subject of concern due to the long degradation time associated with plastic products, increasing use of plastic materials, and inadequate waste handling. The term microplastics is not unitary defined and can refer to synthetic polymer particles with different size ranges, however, often a size less than 5 mm and larger than 0.1 mm is referred to as microplastic (Hartmann et al. 2019). The annual global production of plastics is reaching almost 350 million tones and more than one third is used for packaging products made of polyethylene (PE) and polypropylene (PP) plastics (PlasticsEurope 2018). The aforementioned polymers together with polystyrene (PS) are the most frequently reported types of plastic in marine samples (Hidalgo-Ruz et al. 2012). It has been estimated that the lifetime of plastic can span centuries or even millennia (Barnes et al. 2009), although the lifetime of the plastic material depends on the chemical composition of the material itself and the surrounding environment (Andrady and Neal 2009). Global assessments of floating plastics in the world´s oceans span from 14,400 tons to 268,940 tons and the uncertainty reflects current knowledge gaps in occurrence, distribution, and environmental fate of plastics (Eriksen et al.

2014). It has been estimated that at least 8 million tons of plastics enter the oceans every year from land-based sources (Jambeck et al. 2015).

Deliberately or accidentally released, plastics are transported and spread by currents and winds and fragmented to smaller particles over time (Andrady 2011). These secondary micro-fragments of plastics contribute to an increasing amount of small plastic particles in our oceans (Barnes et al. 2009). A mere physical threat such as entanglement, strangulation, and abrasion of the gastrointestinal tract that plastic debris can pose to organisms is at hand and has been reported to affect different species (Cadée 2002; Laist 1997; Mascarenhas et al. 2004). Additionally, it has also been hypothesized that plastic particles can act as a vector for transferring persistent organic pollutants (POPs) to organisms upon ingestion, after various POPs have been found on marine plastic debris (Carpenter and Smith 1972; Mato et al. 2001; Teuten et al. 2007). Additionally, a risk of leaching plastic additives, monomers, oligomers, and other polymer degradation products from the plastic material into the environment has been recognized by researchers (Gewert et al. 2015; Teuten et al. 2009). The chemical risk that especially microplastics might pose upon ingestion is however controversially debated and currently not fully explored (Koelmans et al. 2016; Ziccardi et al. 2016).

The European Union has adopted a Marine Strategy Framework Directive (MSFD) to protect the marine environment (EU 2008). One of the goals is that by 2020 litter that negatively affects or is likely to negatively affect marine organisms will decline. An important component required to achieve this goal is the characterization of different types of litter, such as microplastics, in the marine environment since that can help to understand source patterns and provide a baseline for future monitoring and evaluation of preventive measures. Currently there exists no standardized method for the sampling of microplastics in any environmental compartment. However, a frequently used method for sampling of microplastics in surface waters is the use of a neuston net or a manta trawl with the most commonly used mesh sizes between 300 – 390 µm (Hidalgo-Ruz et al. 2012; Li et al. 2018). Another technique is pumping water through filters of different mesh sizes using a stationary or submerged pump (Norén et al. 2009; Setälä et al. 2016; Zobkov et al. 2019).

The Baltic Sea is one of the largest brackish waterbodies in the world which is semi-enclosed with a slow water exchange of approximately 30 years with the neighboring North Sea through the Danish straits and a highly urbanized catchment area which is inhabited by about 85 million people (HELCOM 2018). Due to the slow water exchange rate with the North Sea most floating plastic debris can be assumed to originate from local sources of the surrounding countries. Currently HELCOM is working on establishing core indicators for the assessment of marine litter and it has been stated that about 70 % of the litter in the Baltic Sea are made of plastic materials (HELCOM 2018). The occurrence of microplastics has been reported for many marine environments globally (Cozar et al. 2014; Eriksen et al. 2014), but there is little data about the occurrence and identity of microplastics in surface waters of the Baltic Sea (Gewert et al. 2017; Gorokhova 2015), while several studies assessed plastic pollution in sediments and beaches along the Baltic Sea (Esiukova 2017; Hengstmann et al. 2018; Näkki et al. 2019; Stolte et al. 2015).

In this study we therefore aim to 1) study the occurrence of microplastics in surface waters of the Baltic Sea, including Skagerrak and Kattegat, 2) identify the polymer types of detected microplastic particles, and 3) compare the results of the two sampling methods employed, in order to add valuable information to the process of harmonizing sampling protocols. In addition, microplastics down to 0.05 mm particle size were analyzed for the filtering pump.

Materials and Methods

Sampling setup

Sampling was conducted in Skagerrak/Kattegat, Baltic Sea and Gulf of Bothnia in August 2014 using the sailing vessel `Sea Dragon´ (www.panexplore.com). The sampling started in Gothenburg on the Swedish west coast on the 3rd of August and finished in Stockholm located on the Swedish east coast on the 23rd of August. A total of 12 sites were sampled (Figure 1). Sampling was conducted using two methods; a manta trawl and an *in situ* pump (see figure S1 in the supplementary material (SM)). One sampling site spanned over approximately 10 km and 3 samples were taken at each site; the first sample was taken by towing the manta trawl for 60 min at the side of the sailing vessel with a speed between 0.5 and 1.5 m/s., covering 4-5 km of sea surface. The second sample was taken with the filtering pump which filtered approximately 20 m^{-3} of water while the sailing vessel was drifting. For the third sample the trawl was used again as described above (illustration provided in the supplementary material, figure S5). A total of 24 manta trawl samples were taken, however, due to technical difficulties at one site, only 11 pump samples were collected. The sampling sites were selected primarily to give a large cross section of the waters surrounding Sweden and secondarily to match the Swedish Meteorological and Hydrological Institute monitoring stations (smhi.se/klimatdata/oceanografi/havsmiljödata). Necessary permits for sampling national waters were obtained from authorities in Sweden, Denmark and Finland.

Figure 1. Sampling locations as yellow circles (1-12), each location consists of two trawl samples and one pump sample, except sample point 5 where only trawl samples were collected (Google maps®). A detailed visualization of the sampling scheme is given in SM (figure S5).

Manta trawl

The manta trawl consisted of an aluminum frame with a rectangular opening with dimensions 16 cm by 61 cm, and a net with a length of 3 m and a mesh size of 333 µm. The end of the mesh was fitted with a detachable collecting bag with dimensions 30 cm by10 cm. Immediately after sampling the content of the trawl was rinsed with filtered sea water down into the collecting bag. The content of the collecting bag was transferred to a metal sieve with a mesh size of 300 µm by rinsing everything with filtered sea water. Finally, the material on the metal sieve was carefully transferred to glass jars by using metal tweezers and rinsing down the remaining material with filtered sea water. The samples were stored in darkness at room temperature on the boat prior to transport to the laboratory (3-7 days). The volume of water filtered through the trawl was both calculated through multiplying the sampled distance (based on GPS coordinates) with the width of the trawl times half of the height of the trawls opening area, or by using a flow meter (KC Denmark, Silkeborg, Denmark) that was attached to the inlet of the trawl. Half the height of the trawl was chosen because the trawl was often not fully submerged into the water due to wave action.

Filtering in situ pump

The stainless steel *in situ* pump was designed and built by KC Denmark (Silkeborg, Denmark) in collaboration with researchers from the EU CleanSea project (Grant no. 308370). The pump is made up of a motor on top, followed by an inlet grid for water, a filter stack with room for three filters, and a flow meter section at the bottom measuring the sampled water with high precision (for more information see figure S1 in the SM). A stack of three laser cut stainless steel filters, 18 cm in diameter and with mesh sizes of 500, 300 and 50 µm were inserted in the pump before each sampling. Prior to use the filters were cleaned in the laboratory with laboratory detergent and rinsed with ultrapure water. Additionally, each filter was investigated with a stereomicroscope for contamination, wrapped in aluminum foil and placed into metal jars with a lid until sampling. The maximum flow volume of the pump is 20,000 L/h. A digital flow meter records the volume exiting the filter stack and the output can be read in real time with a precision of the flow data of ± 1.8 L.

The total sampling time for the pump at different sites was between 23 and 138 minutes. The sailing boat was drifting during the sampling. For most of the sampling points the 50 µm filter was removed after 838-3 794 liters due to clogging. The sampled water volume for the 300 µm and 500 µm filters ranged from 1 046 to 20 022 liters. The pump with the filter stack was assembled right before the sampling and was put into the water at the side of the boat by a hydraulic lift and a spinnaker pole with the water intake at a depth of approximately 10 – 20 cm below the water surface. After sampling, the filters were carefully removed from the pump and stored up-right at room temperature in metal jars prior to transport to the laboratory (3-7 days). A 500 µm and a 300 µm filter were left standing open on deck of the vessel for the time of pump sampling to serve as sampling blanks.

Identification of microplastic particles and fibers

Samples were stored at 4 °C until analysis. Large organic material like sea grass, feathers, small fishes etc. were manually picked out from the samples with tweezers, rinsed with ultrapure water to avoid loss of attached particles or fibers, and transferred into empty glass jars. The trawl samples were rinsed down with ultrapure water onto 0.3 mm pre-cleaned stainless steel filters, same type as the metal filters that were used for the pump sampling (KC Denmark, Silkeborg, Denmark), and subjected to visual examination by stereomicroscopy. In order to compare the pump and trawl results, the counts of the 300 µm and 500 µm pump filters were summarized and reported as ≥ 0.3 mm. To improve and accelerate the visual analysis of the 0.05 mm pump filters, the material on the filters were rinsed down with ultrapure water into glass jars and the content of the glass jars was filtered through glass fiber filters (0.2 µm, Whatman). The glass fiber filters were transferred to glass petri dishes and closed with a lid. The preceding procedures were conducted under the fume hood to minimize sample contamination from the lab. All filters were visually examined with a stereomicroscope (Stemi DRC Zeiss 25x magnification (10 ocular, 2.5 lens)). The visual examinations could not be carried out under a fume hood, but to minimize sample contamination in this step, a lab coat and nitrile gloves were worn at all time. One set of filters was left standing in the laboratory as a laboratory blank sample and visually investigated with a stereomicroscope as done for the samples.

To qualify as anthropogenic microlitter the particles had to show an absence of organic structure such as cell walls. Synthetic fibers were separated from natural fibers by having an equal and even thickness throughout the entire length and a homogenous coloring, whereas natural fibers such as cotton were identified as flatter in their structure. Fibers were only counted if longer than 1 mm and transparent fibers were excluded. The qualitative counting of anthropogenic particles was performed and calibrated between two scientists in order to agree on a protocol that resulted in satisfying results. The agreed protocol was similar to other protocols described in the scientific literature (Hidalgo-Ruz et al. 2012). The microplastic particles were categorized based on color into blue, white, black, other plastic particles (e.g. mixed color particles) and other non-plastic particles. The shape of the particles was not noted. The particle and fiber counts of all samples were corrected for sampling and laboratory blanks by subtraction.

Further plastic polymer identification of microplastic particles and fibers was done for all first trawl samples at each sampling location using near-infrared hyperspectral imaging (Umbio Inspector, Sisuchema Specim, Oulu, Finland) as previously described by Karlsson et al. (2016). To eliminate background scattering of the metal filters, the particles and fibers were transferred with tweezers into glass petri dishes and closed with a glass lid. The petri dishes were stored in a 4 °C refrigerator until NIR hyperspectral image analysis.

Results and Discussion

Occurrence of microplastic particles and fibers

The microscopic examination of sampling blanks and laboratory blank showed that there was only a small potential for contamination of the samples during the sampling and laboratory procedure. On average we found 3 fibers and no particles in all blanks. The possible contamination with fibers of the trawl samples by rinsing down the trawl with filtered seawater was negligible because the used volume for rinsing was less than 0.01% of the sampled volume. The majority of trawl samples (88%) contained microplastic particles; only 3 out of 24 samples had no microplastic particles. In pump samples with a mesh size of ≥ 0.3 mm 91% of the samples contained microplastic particles. The median microplastic particle concentration per cubic meter (m^{-3}) surface water in manta trawl samples was 0.04 microplastics m^{-3} and for the corresponding mesh size (≥0.3 mm) using the pump 0.10 microplastics m^{-3} (Table 1). For seven of the locations an additional filter with a mesh size of 0.05 mm was used during the pump sampling. The median concentration of microplastics in this size fraction of the pump was 3.74 particles m^{-3}. The concentration of microplastic particles were in general, with exception of the Kattegat sample, higher in the 50 – 300 µm fraction compared to ≥ 0.3 mm size fraction of the pump. The median microplastic particle concentration in the 0.05 mm pump fraction was, however, not significantly higher than the total median concentration in the ≥ 0.3 mm size fraction of the pump, but significantly higher than the total median concentration sampled by the manta trawl (Kruskal-Wallis test: $p=0.0054$).

The maximum abundance of microplastic particles between stations was not coincident for trawl and pump samples. In pump measurements (≥ 0.3 µm) the highest abundances of microplastic particles were observed in the Skagerrak/Kattegat area, while in the trawl samples the highest particle concentrations were found in the southern Baltic Proper and the western Gotland Basin. In pump samples the location with the highest abundance of microplastics also differed according to the filter size used. For instance, for the 0.05 mm size fraction the southern Baltic Proper (sample ID 3) showed the highest concentration of microplastics m^{-3} in contrary to the ≥ 0.3 mm fraction that was highest in Skagerrak and Kattegat. The replicate samples taken with the trawl showed a high variation, which is quite characteristic for microplastic pollution, but no significant differences in microplastic counts between locations were observed for the trawl samples (Kruskal-Wallis: $p < 0.05$, followed by Dunn's multiple comparison test: $p > 0.05$). This emphasizes the need for replication in future studies aimed at investigating differences between microplastic concentrations.

Table 1. Microplastic particle counts and concentrations expressed as counts per cubic meters (m^3) for twelve sampling sites, using two sampling methods and different mesh sizes.

		Trawl[a] (0.3 mm)		**Pump (≥ 0.3 mm)**		**Pump (0.05 mm)**	
ID	**Site**	Particle count	Concentration	Particle count	Concentration	Particle count	Concentration
1	Skagerrak	3 9	0.02 0.05	8	2.59	n.s.	n.s.
2	Kattegat	2 4	0.01 0.02	11	10.5	4	3.82
3	Southern Baltic Proper	6 9	0.03 0.04	2	1.47	10	11.9
4	Southern Baltic Proper	20 29	0.16 0.16	2	0.07	n.s.	n.s.
5	Western Gotland Basin	86 24	0.46 0.13	n.s.	n.s.	n.s	n.s.
6	Bothnian Sea	5 6	0.12 0.04	0	0	0	0
7	The Quark	7 4	0.04 0.02	1	0.10	3	1.45
8	Bothnian Sea	7 9	0.05 0.05	5	0.49	n.s.	n.s.
9	Bothnian Sea	9 7	0.06 0.03	2	0.05	5	1.32
10	Northern Baltic Proper	0 1	0 0.01	2	0.10	11	8.80
11	Eastern Gotland Basin	1 0	0 0	1	0.05	n.s.	n.s.
12	Northern Baltic Proper	2 3	0.01 0.04	1	0.05	116	70.3
	Median	6	0.04	2	0.10	5	3.82
	Quartiles (1st; 3rd)	2.75; 9	0.02; 0.06	1; 3.50	0.06; 0.98	3.50; 10.5	1.38; 10.4

n.s.: no sample was taken, [a] two trawl samples per site were taken

Median concentration of fibers, including natural and synthetic fibers, was 0.35 fibers m^{-3} in the manta trawl samples, 2.74 fibers m^{-3} for the pump samples with a filter size of ≥ 0.3 mm, and 50.4 fibers m^{-3} in 0.05 mm pump samples (Table S3 of the SM). The total median concentration of fibers m^{-3} was significantly higher in pump samples for both mesh sizes compared to the trawl (Kruskal-Wallis: $p > 0.001$). Although it has to be kept in mind that the larger mesh sizes (≥ 0.3 mm) do not representatively sample fibers due to the small diameters of fibers and attachment to biological material, therefore the data might not be completely reliable.

The locations with the highest amount of microplastics m^{-3} in pump samples also matched the highest amount of fibers m^{-3} in pump samples (sample ID 1, 2, and 3), regardless of the used mesh size. In the trawl samples the location with the highest abundance of fibers m^{-3} differed from the location with highest microplastic abundance. The Bothnian Sea (sample ID 8) and the Skagerrak (sample ID 1) had the highest amount of fibers m^{-3} in trawl samples. The fiber counts in the trawl samples did not differ significantly among the sites (Kruskal-Wallis: $p = 0.1769$). The majority of fibers in pump samples and trawl samples were categorized as synthetic fibers by visual examination with the stereomicroscope (see figure S2, S3, and S4 of the SM). In the 0.05 mm pump samples most fibers were synthetic and less than 15 % were identified as natural. In one sample, at Kattegat, a slightly higher percentage (27 %) of the fibers was identified as natural fibers (Figure S2). The amount of natural fibers in the samples is, however, likely to be an underestimation because translucent fibers were not counted, and a lot of natural fibers appear translucent. Most of the identified synthetic fibers in all samples were black or blue, which can indicate ropes as a potential source of these fibers because these colors are very common for boat ropes and fishing gear when comparing to sales items in marine stores.

The wind speed varied throughout the sampling period and a decline of microplastic particles in the trawl measurements could be observed with increasing wind speed. A significant negative correlation was found between the wind speed and the abundance of microplastic particles (Spearman correlation: p = 0.0021 (two-tailed); r = - 0.60) (Figure 2).

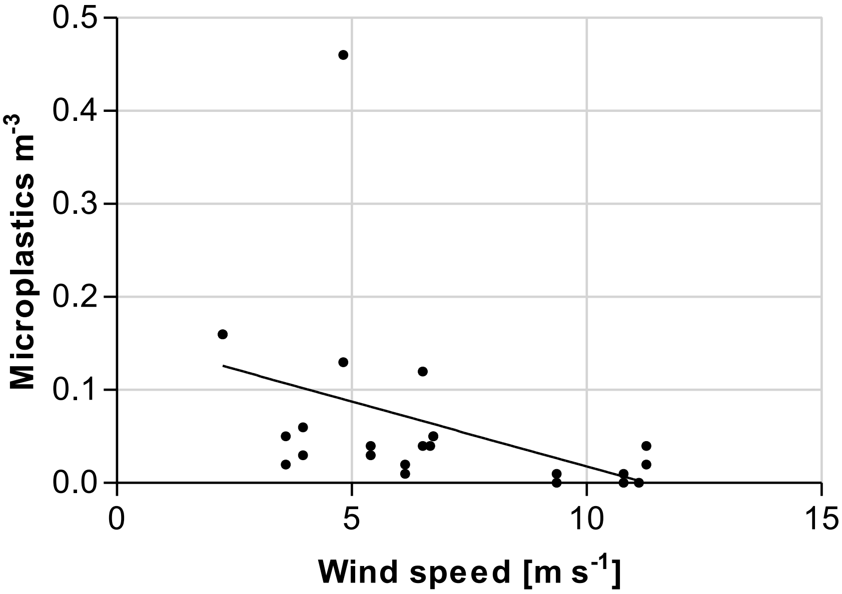

Figure 2. Concentration of microplastic particles (count per m^{-3}) in trawl samples plotted against wind speed ($m\ s^{-1}$) at sample location and time. A linear trend line is inserted for visualization of the negative trend.

Microplastic characterization in trawl samples

Particles that were identified as microplastics by visual inspection, as well as ambiguous particles, were analyzed further using near-infrared hyperspectral imaging to identify the polymer type. Microplastic particles were classified as PE, PP, PS, and polyamide (PA) or unidentified based on calibration with pristine plastic pellets of the respective polymer type as a reference material (Karlsson et al. 2016). A total of 137 particles were analyzed of which 8 particles (6%) could not be designated to a certain polymer type (unidentified polymer). The majority of particles consisted of PE plastics (65 %) followed by PP plastics (21 %), which is in line with other studies that have reported PE and PP plastics as the main plastic types in trawl samples (Gewert et al. 2017; Hidalgo-Ruz et al. 2012). A higher abundance of PE and PP plastics has been reported also in stratified water samples (Zobkov et al. 2019) and in different fish species from the Baltic Sea (Rummel et al. 2016). The spectral quality for some of the particles did not allow for separation of the polymers PP and PE (PP/PE). The composition of identified plastic polymers varied among the sampling locations (Figure 3). For instance, PS was only found in two out of eleven trawl samples and no polyamide was found in any of the samples. However, not all of the plastic particles were identified in each sample; therefore the composition might not be directly comparable and is likely not representative for all of the samples. The number of particles for each polymer type were generally less than 10 per sample, except for two samples, which also hampers further statistical evaluation as described by Karlsson et al. (2020).

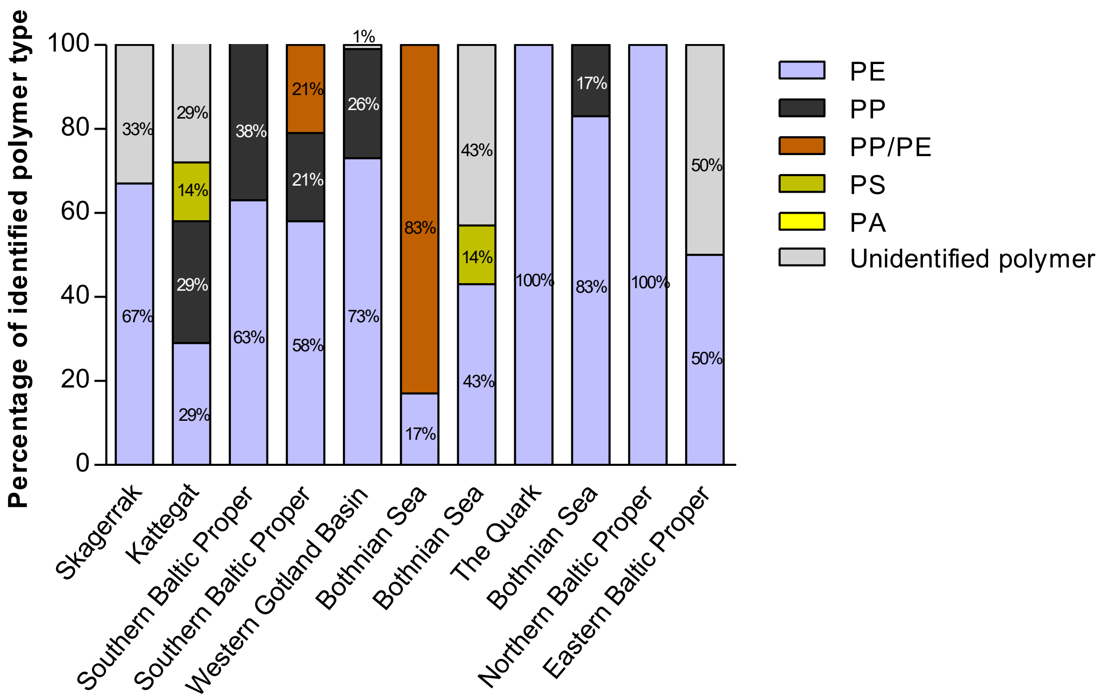

Figure 3. Identified microplastic particles from eleven individual trawl samples divided into polymer classification (% of total).

Comparison of sampling devices

Although the concentration varies between different locations, the low particle counts per sample, and the variation in sampled volumes make a direct comparison of the sampling methods difficult, the pump (≥ 0.3 mm) resulted in notably higher concentrations than the trawl in 4 locations; Skagerrak, Kattegat, the Southern Baltic Proper (ID 3) and the Bothnian Sea (ID 8). Overall, the concentration of microplastic particles was higher in pump samples compared to trawl samples in ten out of eleven sampling sites (Figure 4). In another study which compared a manta trawl (333 µm) and a submerged pump (300 µm) for sampling of microlitter in the Gulf of Finland, the results obtained by both devices were similar (Setälä et al. 2016). The sampling duration was much shorter (10 min for the manta trawl) compared to the present study, and thus also the sampled water volume (10 – 139 L for the pump) was less compared to the herein sampled volume (1046 – 20 022 L for the pump). In the present study the highest difference in microplastic concentration comparing a pump sample and the average of two trawl samples from the same sampling site was 700 fold (Kattegat). The higher abundance of microplastic particles in the Skagerrak, Kattegat and Southern Baltic Proper area in the present study were, however, not exceeding reported concentrations from other studies in these areas (Bagaev et al. 2018; Norén et al. 2009). Besides a small difference in mesh size, the trawl skims the water surface covering a larger area compared to the pump which is stationary submerged into the water surface with only a small drift during the sampling time. Therefore, heterogeneous distribution of microplastic pollution would be better captured using the trawl method. Interestingly, the water volume sampled by the trawl was on average 180 m^3 compared to the average volume of 13 m^3 for the pump. This is a difference of a factor of fourteen between the sampled volumes. However, this was not reflected in microplastic counts in the samples. The amount of counted microplastic particles in trawl samples was in general less than fourteen fold greater compared to pump samples. The higher volume of sampled water by trawl did not lead to a higher concentration of plastic particles compared to pump samples. It has to be noted that there is a greater uncertainty when estimating the volume sampled by the trawl compared to the volume sampled by the pump, due to the differences in submersion. Depending on the wave action the trawl was not consistently submerged at the same height of its frame, this leads to a greater uncertainty in the calculation of the sampled volume. Hence, the actual volume sampled by the trawl is likely to be smaller than the calculated one. Therefore, the microplastic concentrations of trawl samples might be more similar to the concentrations calculated for the pump samples. Nonetheless, both sampling devices are more suitable for surface sampling of microplastics under relatively calm weather conditions. With greater wave action the trawl tends to bounce on the water surface. Whereas a problem with the pump is that air can get sucked in when the waves are higher, which negatively affects the certainty of the sampled volume. The relatively heavy weight of the device itself might be a disadvantage compared to the trawl; two people were necessary to lift the pump into the water. The handling of the samples and the sampling itself is quite convenient for both sampling devices. Although a blank for the trawl sampling was not taken, there might be a slightly higher risk for contamination when using the manta trawl because the rinsing procedure and transferring the sampled material from the collecting bag into a container after sampling takes a bit longer than taking out the set of filters from the pump. Another advantage of the pump is that it can be used to sample in varying depths and simultaneously collecting several size fractions, which is not possible with the manta trawl. Further comparison of the two sampling devices under more controlled conditions are presented elsewhere (Karlsson et al. 2020).

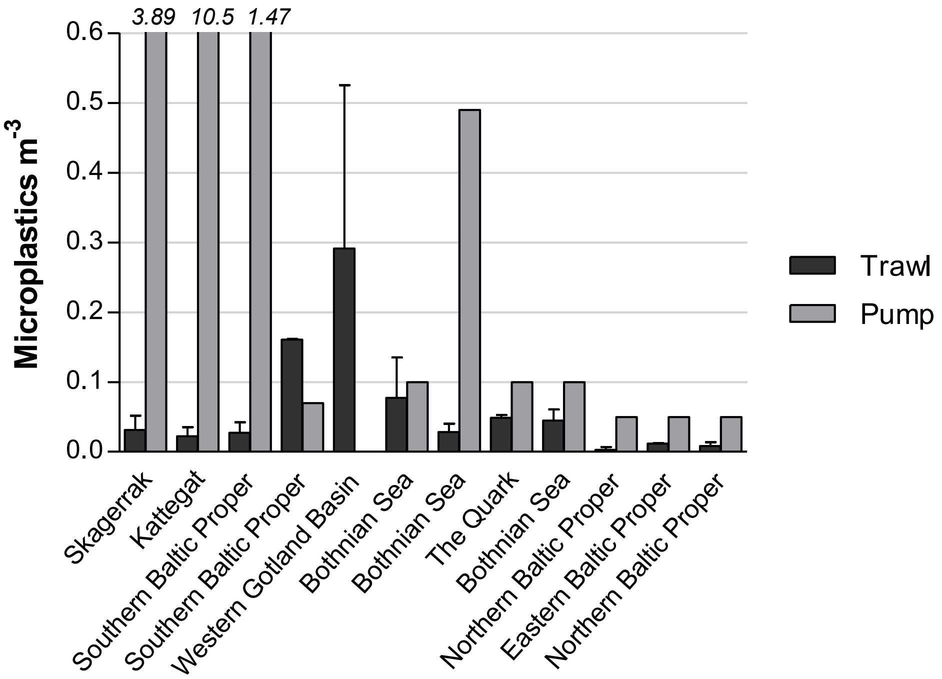

Figure 4. Number of microplastic particles per cubic meter for the trawl (n=2, 0.3 mm) and pump (n=1, ≥ 0.3 mm) samples for twelve sampling sites. The mean values for the trawl samples (n = 2) from each site are presented with the standard deviations given as error bars. No pump sample was taken at Western Gotland basin. Numbers in italic shows results out of scale.

Comparison to other studies

Although the Baltic Sea has been declared as one of the most polluted seas in the world (HELCOM 2010), there are not many studies conducted so far on microplastic pollution in the waters of the Baltic Sea that cover a large area within one sampling campaign. To date there have been two studies that sampled over a larger area of the Baltic, similar to the area presented here (Bagaev et al. 2018; Norén et al. 2009), whereas other studies focused on specific parts of the Baltic Sea (Gewert et al. 2017; Gorokhova 2015; Setälä et al. 2016; Zobkov et al. 2019). The sampling techniques differed greatly among the above mentioned studies which makes a direct comparison difficult and results need to be interpreted carefully. However, a comparison between the conducted studies in open water of different regions of the Baltic Sea shows a wide range of concentrations of reported microplastic particles ranging from 0.012 microplastic particles m^{-3} in trawl samples (≥ 0.3 mm) of the present study to 20,280 microplastic particles m^{-3} in pump samples (20 µm mesh size) (Norén et al. 2009) (Figure 5). It has to be noted that in contrary to the present study, the study of Norén et al. (2009) and Setälä et al. (2016) also included black combustion particles which were the most abundant among the counted particles in some of the samples. It is notable that with decreasing mesh size the abundance of microplastic particles increases significantly. This effect has also been reported in other studies, and the present study corroborates the need for integrating smaller mesh sizes into the sampling regimen of microplastics. Especially fibers will slip through mesh sizes that are currently in use, due to their small diameter (µm-nm range) and shortness. Fibers are also more likely to adhere to, for example, biological material and therefore might not be sampled representatively. By use of a smaller mesh size a higher degree of accurate quantification of fibers is possible. An important point to consider when using smaller mesh sizes is the general composition in the water phase that should be sampled. If the water phase contains a large amount of organic material, a filter or net with a smaller mesh size will rapidly become clogged. In fact, this could be observed in the present study when utilizing a 0.05 mm filter. The volume which was filtered with the 0.05 mm filter was always less than the volume sampled with a ≥ 0.3 mm filter due to fast clogging of the 0.05 mm filter. However, other factors than the mesh size influence the detected concentrations as well, and abundances can vary several orders of magnitude even by using the same mesh size and sampling technique (see figure 5).

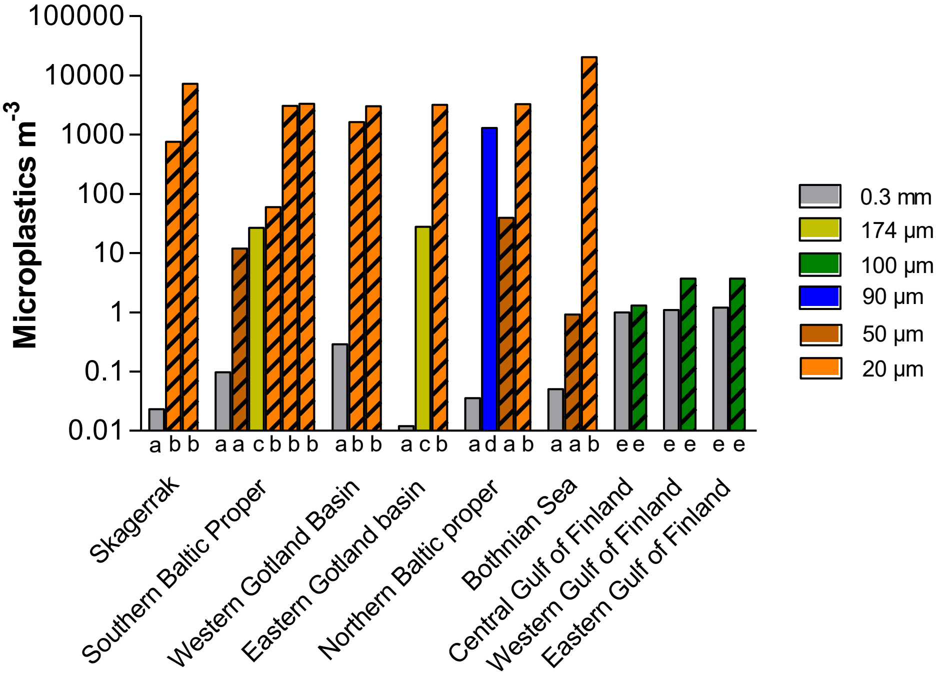

Figure 5. Concentration of microplastic particles per cubic meter in surface or near surface open water in Skagerrak and the Baltic Sea presented on a logarithmic scale, reported by different studies using different mesh sizes and techniques. Striped bars represent samples that were obtained by pump sampling. a: this study; trawl samples are presented as mean values of two replicates, b: Norén et al. (2009), c: Bagaev et al. (2018), d: Gorokhova (2015), e: Setälä et al. (2016).

In a study by Gewert et al. (2017), which only focused on the Stockholm archipelago, an overall median concentration of 0.6 microplastic particles m^{-3} has been reported by manta trawl sampling, which is an order of magnitude greater than the median concentration of 0.04 microplastic particles m^{-3} found in our study by sampling with a manta trawl. The highest concentrations of 7.73 and 4.93 microplastic particles m^{-3} were detected in direct proximity to the city of Stockholm (Gewert et al. 2017). It should be noted that several studies have observed that microplastic concentrations increase with decreasing distance to urban areas with pollution sources such as industry and wastewater treatment plants (TM Karlsson et al. 2018; Magnusson and Norén 2014; Talvitie et al. 2015).

The patchiness of microplastic distribution was reflected in some replicate trawl samples from the same site in the present study. The greatest difference with a factor of four was observed in trawl samples from the Northern Baltic Proper (ID 12). Wind, for example, has been observed as an important variable for surface water sampling due to wind-induced mixing (Kukulka et al. 2012) as well as currents. The inherent variation in water conditions most likely results in large temporal and spatial differences in the abundance and distribution of microplastics. Standardized protocols for sampling and analysis are needed as well as studies aiming at assessing the microplastic concentration baseline variations.

Conclusions

The data reported in this study confirms that microplastic contamination is ubiquitous in Swedish waters. It also indicates a higher accumulation on the Swedish west coast, which is known to be particularly affected by macrolitter. The present study highlights the importance of using standardized methodologies in order to achieve comparable data, since the results differed between sampling devices. Overall, the pump sampling resulted in higher detected concentrations of microplastic particles and fibers than the manta trawl sampling. It was also noted that the number of detected particles and fibers increased by use of a smaller mesh size. The patchiness associated with microplastic pollution is an urgent methodological challenge that needs to be addressed in future scientific studies in order to allow for the assessment of temporal and spatial trends.

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